Net-Zero Energy (NZE)
Installations & Deployed Bases Workshop

Colorado Springs, Colorado, USA
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Presented by:

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of
Building Envelope Solutions, Inc.

1. Q&A after lunch
2. Resources " * "
   - Documents available on CD or by email.
   - Physical properties matrix

Introductions

Richmond Middle School

Richmond Middle School

Richmond Middle School

Richmond Middle School

First Instance Testing

Compliance Test – Richmond Middle School

Compliance Test – Richmond Middle School

Compliance Test – Richmond Middle School

Energy Improvement vs. Cost

Richmond Middle School (Whole School) ~103,860 sq. ft.

80% better than typical 39% better than ASHRAE

East Wing (QA Zone test) 23,579 sq. ft. - 60% better than typical construction

East Wing with AHU's covered - 85% better than typical 55% better than ASHRAE

The entire wall system installed by the contractor was about $1.35 per square foot of floor area.

The net up-front construction savings for a "right-sized" HVAC System would be about $262,500

Energy Improvement vs. Cost

Richmond Middle School (Hanover, NH)

The first winter (2007-2008) the fuel cost for the entire school was 14,000, or about $.13/sq. ft.

Overview

- A brief history of the material
- What is polyurethane foam?
- Application methods
- How does foam facilitate high-performance buildings?
- What can it achieve?
- What are the technical barriers?
- High-performance show and tell citing real-world projects

The History of Polyurethane foam

History

- Polyurethanes were originally developed in the late 30s in Leverkusen, Germany (Otto Bayer)
- The technology arrived in the US after World War II (Mobay Chemical)
- Flexible foams (furniture) were prevalent before their use as acoustic and thermal insulations.
- Rigid Foam, medium density
  - Spray applications first began in 1950 in North America
  - 1970 - beginning of current use in construction

**Handouts – "Common Uses of Polyurethane Foams" – Page from FOAM-TECH Website; "Urethane Foams"*

*Samples

The History of Polyurethane foam

The following table shows how polyurethanes are used (US data from 2004):[26].

Application	Amount of polyurethane used (millions of pounds)	Percentage of total
Building & Construction	1,459	26.8%
Transportation	1,298	23.8%
Furniture & Bedding	1,127	20.7%
Appliances	278	5.1%
Packaging	251	4.6%
Textiles, Fibers & Apparel	181	3.3%
Machinery & Foundry	178	3.3%
Electronics	75	1.4%
Footwear	39	0.7%
Other uses	558	10.2%
Total	5,444	100.0%

In 2007, the global consumption of polyurethane raw materials was above 12 million metric tons,

The size of the industry

The History of Polyurethane foam

- BES/FOAM-TECH has a 30-year history of completed installations
  - Thousands of residences and multi-family complexes
  - Specialty applications (the Big Dig, DARPA)
  - Museums and art galleries (the Guggenheim)
  - Extreme environments (Antarctica)
  - Historic (VT & NH Historical Society Centers, many national register sites)
  - Schools and colleges
  - Hospitals and extended care facilities
  - Industrial, research, & marine applications
  - Food storage and processing

Polyurethane foam

A. Common examples

B. The material

C. The physical properties (or the physics) of polyurethane foam products

Polyurethane foam

Common trade names and products

- Polyurethanes, urethanes
- Polyisocyanurates, polyiso board
- Icynene™
- SEALECTION 500™
- Corbond™
- Comfort Foam™
- SUPERGREEN FOAM™
- INSTA-FOAM™
- Walltite™
- Heatlok™
- Thermax™

Polyurethane foam

Polyurethanes (a reaction polymer)

- Isocyanates
- Polyols
- Chain extenders & cross linkers
- Catalysts
- Surfactants

Polyurethane foam

The Material

- Polyurethanes are plastics manufactured from two basic raw materials - sugar or other bio-based material for polyol, and oil by-products for isocyanates. All members of the urethane family of plastic materials include isocyanurates (~50%).
- The bubbles or hollow cells are created by introducing "blowing agents" – primarily low-conductivity gases or water. These boil at atmospheric pressures from the heat of the exothermic reaction to form the bubbles.

Polyurethane foam

Cell types

- Closed-cell foams with low-conductivity gasses in the bubbles have higher R-values, high resistance to air and vapor flow, and are very strong. Closed-cell foams will be at least 1.85#/cu. ft. There are closed-cell foam products that are not filled with low-conductivity gasses.
- Low density foams with open cells, usually water-blown, have R-values typical of other insulation materials with air in the interstitial spaces. They are permeable to vapor transmission, and are non-structural. They can, however, have a high resistance to air flow. Open-cell foams are usually less than 1#/cu. ft.

**Handout – FAQ response from F-T Website –"What is the difference between open-cell and closed-cell urethane foams?"*

Polyurethane foam

Cellular geometry

- Urethane foam approaches a close-packing geometry when it is formed without restraint.
  - Cells closest to spherical shapes are the strongest.
  - Elongated cells are strongest in the line of the “rise,” like wood fibers.
- Open or broken cells have less strength.

Polyurethane foam

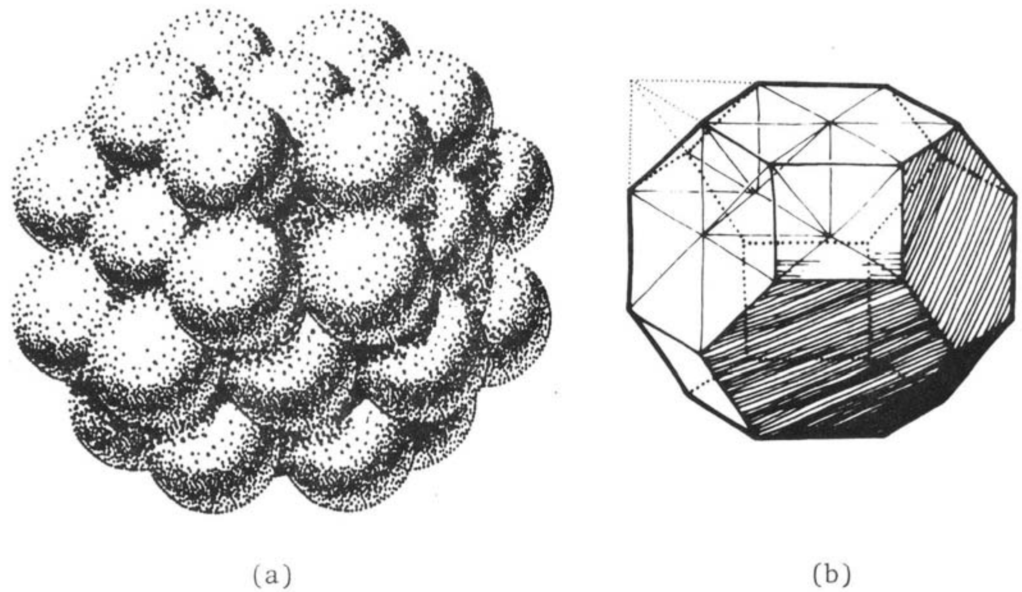


Figure 4-26. An aggregation of thirty-eight (thirty-two external plus six internal) ccp *spheres with certain sphere centers interconnected to define* 4.6^2.

CELL GEOMETRY

Polyurethane foam Physical Properties

- Density
- Strength
- R-value
- Air permeability
- Vapor permeability
- Water permeability
- Speed of the chemical reaction
- Fire resistance

US Army Corps of Engineers ERDC-CERL

Physical properties / characteristics Types of materials	Installation form/method	Density (#/cu.ft.)	Compressive Strength (PSI)	Blowing Agent	Expansion / packing (volume) Before/after
Glass fiber	Blankets	1 - 5	0	Air	1 : 1
	Blown in	1 - 2	0	Air	1 : 1
Rockwool	Blankets	1 - 2	0	Air	1 : 1
	Blown in	1 - 5	0	Air	1 : 1
Cellulose	Blown in	0.5	0	Air	1 : .5
	Dense-pak	.5 to 1.5	0	Air	1 : 1
	Wet spray	1 to 1.5	0	Air	1 : 1.5
Polyurea	Injected	1 to 1.5	0	Air	1 : 40
Expanded polystyrene	Sheet goods	.5 to 1.5	10 - 20	Steam	1 : 35
Extruded polystyrene	Sheet goods	1 - 5	20 -30	LCG	1 : 25 to 35
Foamglass	Sheet goods	2 - 5	20 -30	Air	1 : 15 to 20
Polyisocyanurate	Sheet goods	1.85 - 3.0	20 -30	LCG	1 : 30
Bulk Polyurethane foam					
Options	All forms	.5 to 100	5 - 100	H2O/LCG	1 : 1 to 100
Spray-applied open-cell polyurethane	Spray-applied	0.5	5	H2O	1 : 100
Cavity-fill open-cell polyurethane	Injected	0.5	5	H2O	1 : 100
Spray-applied closed-cell polyurethane	Spray-applied	1.85 - 3.0	20 -30	H2O/LCG	1 : 25 to 35
Cavity-fill closed-cell polyurethane	Injected	1.85 - 3.0	20 -30	H2O/LCG	1 : 25 to 35
SIPs (Wood/gypsum/metal faces)	Injected	2.0 to 2.5	20 -30	H2O/LCG	30
Kit/can Polyurethane foam					
Two-component expanding	Disposable Kit	1.65 - 2.0	15 - 20	H2O/LCG	1 : 1
Urethane sealant					
Single-component expanding	Can dispenser	1 - 1.5	10 - 15	H2O	1 : 1
Single-component non-expanding	Can dispenser	1 - 1.5	10 - 15	H2O	1 : 1
Urethane caulk	Tube	N/A	N/A	N/A	1 : 1

* LCD = Low-conductivity gas

Physical properties / characteristics Types of materials	Cure type	U-value	R-value	Vapor permeable	Air permeable	Flamability
Glass fiber	N/A	0.30	3.30	Yes	Yes	Low
	N/A	0.30	3.30	Yes	Yes	Low
Rockwool	N/A	0.29	3.50	Yes	Yes	Low
	N/A	0.29	3.50	Yes	Yes	No
Cellulose	N/A	0.29	3.50	Yes	Yes	Low
	N/A	0.29	3.50	Yes	Yes	Low
	Air dry	0.29	3.50	Yes	Yes	Low
Polyurea	Air dry	0.29	3.50	Yes	Yes	No
Expanded polystyrene	Thermoset	0.25	4.00	Yes	No	Fire retarded
Extruded polystyrene	Thermoset	0.20	5.00	No	No	Fire retarded
Foamglass	Cooling	0.29	3.50	No	No	No
Polyisocyanurate	Exotherm	0.17	6.00	No	No	Fire retarded
Bulk Polyurethane foam						
Options	Exotherm	1.0 to .13	1 to 7.5	Varies	No	Varies
Spray-applied open-cell polyurethane	Exotherm	2.8 to 2.6	3.6 to 3.8	Yes	No	Fire retarded
Cavity-fill open-cell polyurethane	Exotherm	2.8 to 2.6	3.6 to 3.8	Yes	No	Fire retarded
Spray-applied closed-cell polyurethane	Exotherm	0.15	6.50	No	No	Fire retarded
Cavity-fill closed-cell polyurethane	Exotherm	0.15	6.50	No	No	Fire retarded
SIPs (Wood/gypsum/metal faces)	Exotherm	.15 to .13	6.5 to 7.5			
Kit/can Polyurethane foam						
Two-component expanding	Exotherm	0.17	6.00	No	No	Fire retarded
Urethane sealant						
Single-component expanding	Exotherm	N/A	N/A	No	No	Fire retarded
Single-component non-expanding	Exotherm	N/A	N/A	No	No	Fire retarded
Urethane caulk	N/A	N/A	N/A	No	No	N/A

* LCD = Low-conductivity gas

Polyurethane foam

Physical properties effect performance.

When is closed-cell foam a vapor barrier?

- A nominal 2# foam formulation in the lab (core with skins removed) ~ 2.5”
- A nominal 2# foam formulation sprayed onto gypsum board ~ 1.75”
- A nominal 2# foam formulation sprayed onto concrete block ~ 1”

Polyurethane foam

- Compatible with most substrates
- Methods
  - Spray-applied
  - Injected into building cavities on site
  - Air sealant (“spritz”)
  - OEM
    - Stressed-skin panels (Structural insulated panels or SIPs – prefabricated, but field installed and sealed)
    - Board stock (Thermax, Ultra-R, etc.)
- Delivery systems
  - Portable units (Kits and Cans)
  - Bulk (Low-tech and high-tech machine processing equipment)

Polyurethane foam

Mobile Spray Rig (Bulk foam)

Polyurethane foam

Two-component kit foam
(Kits and cans)

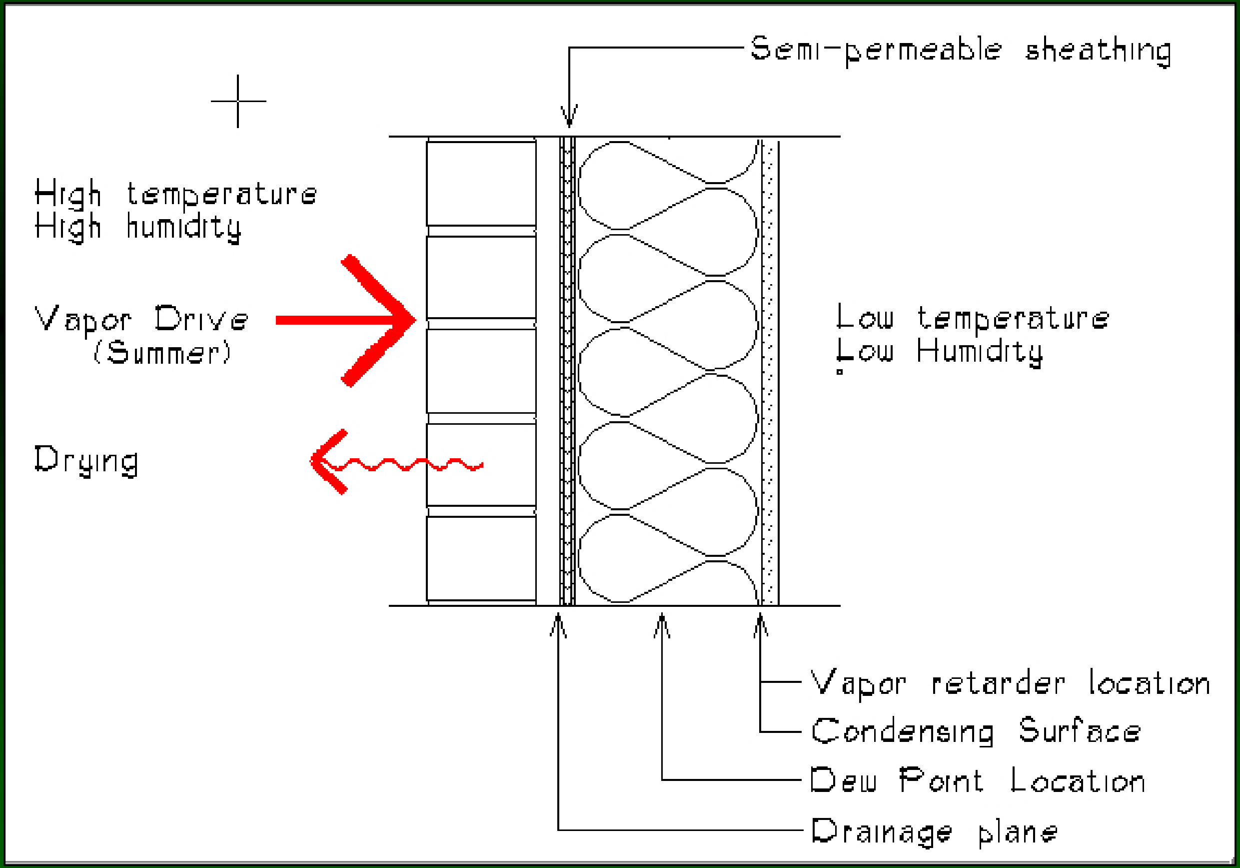
How does foam facilitate high-performance buildings?

1. Foam is a complete building envelope system
   - Foam provides a complete air, vapor, water, and insulation barrier in one material installed by one trade.
   - Some call it "the perfect wall" when compared to alternate multi-component systems installed by multiple trades.
   - Solves bi-directional dew-point issues (intermittent wetting and drying cycles)
   - High R-Value per inch, not subject to R-value drift

How does foam facilitate high-performance buildings?

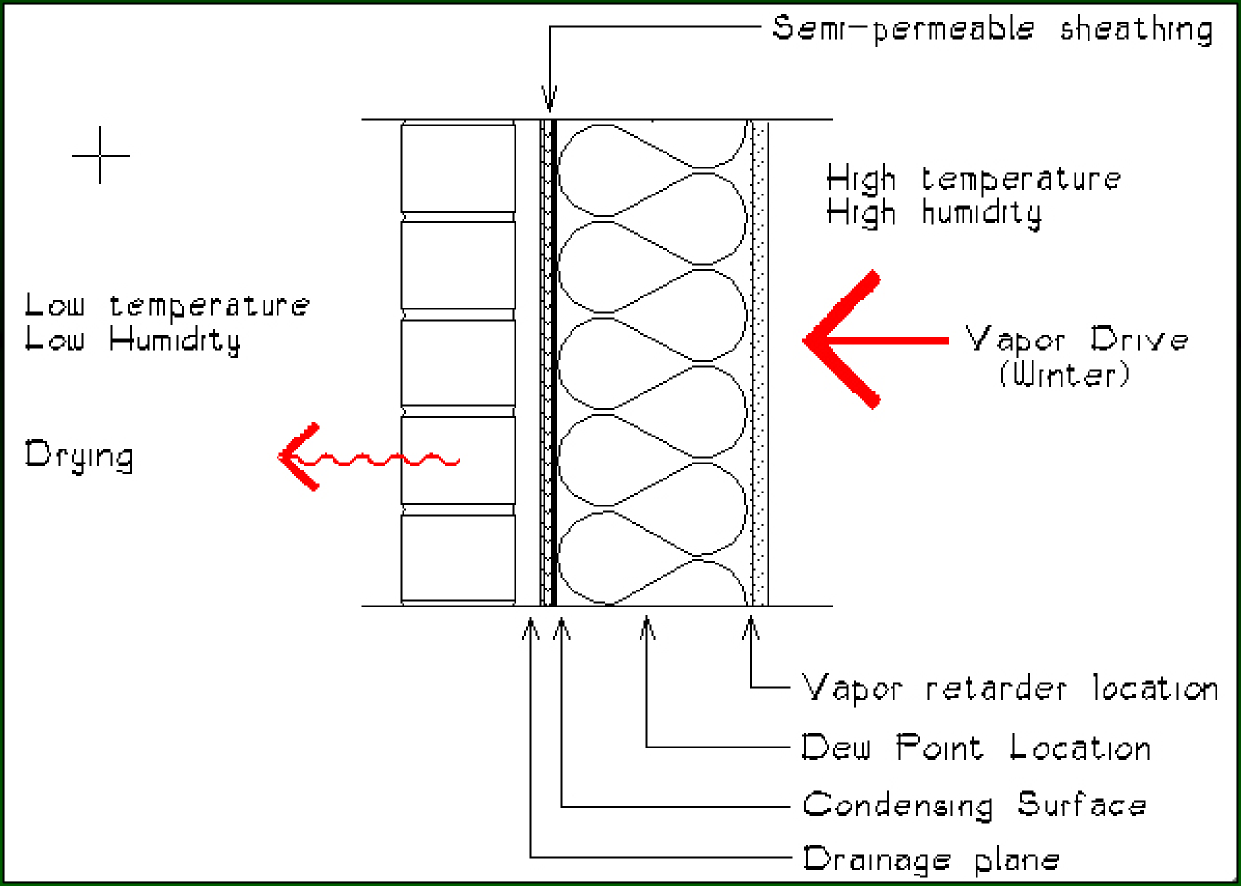
Bi-directional vapor drive

How does foam facilitate high-performance buildings?



One-way drying/wetting (Summer-cooling)

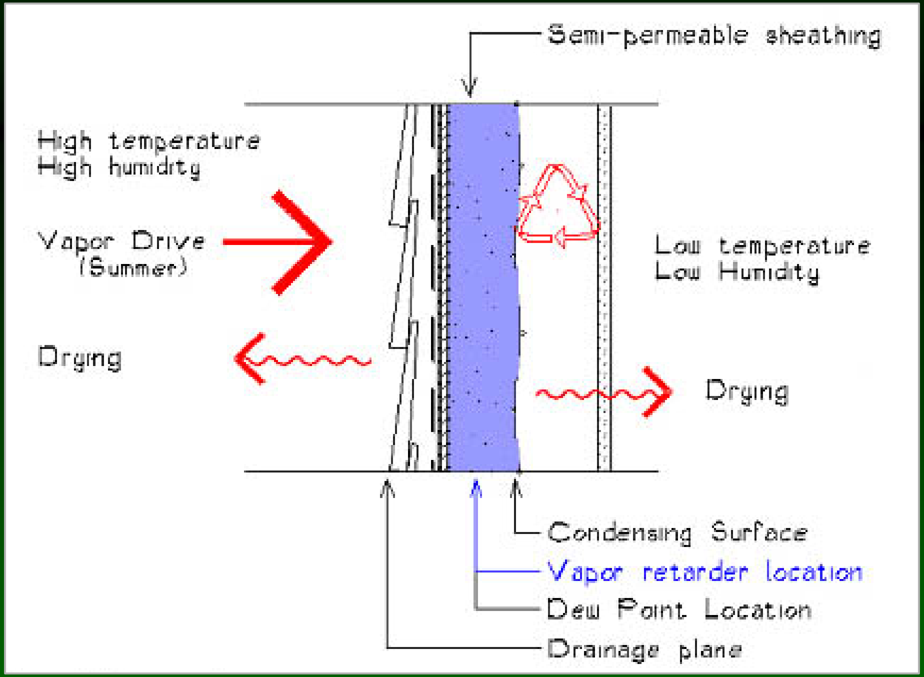
How does foam facilitate high-performance buildings?



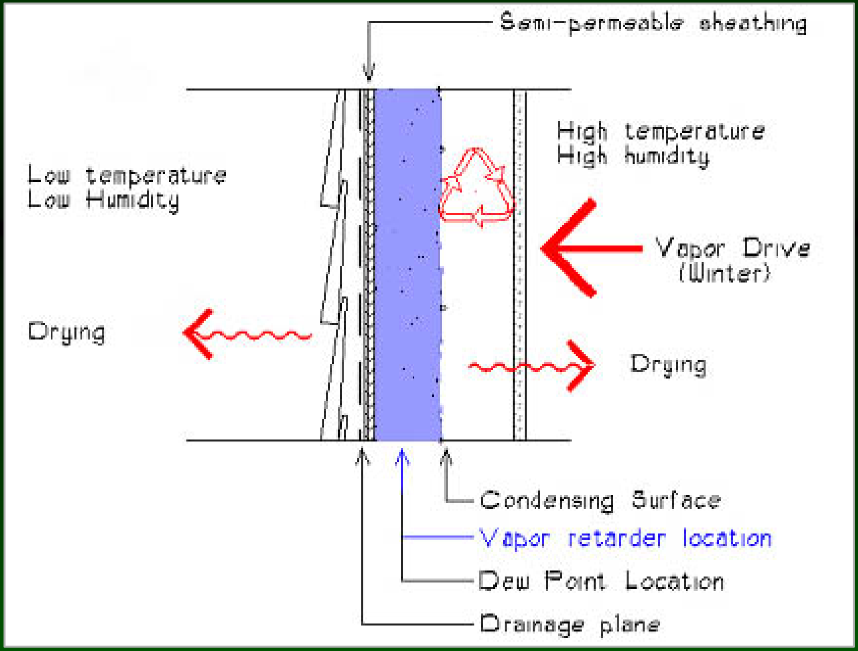
One-way drying/wetting (Winter-heating)

How does foam facilitate high-performance buildings?

Bi-directional Drying in Northern/Mixed



Summer/AC



Winter

How does foam facilitate high-performance buildings?

R-value varies with the air permeance of the insulation

How does foam facilitate high-performance buildings?

R-19 loose-fill, glass-fiber insulation:

Metering Chamber (F)	Climate Temp (F)	R-Value
70	44.6	17.8
70	32.0	16.1
70	26.8	14.1
70	8.6	12.0
70	-4.0	10.6
70	-18.4	9.2

Oak Ridge National Laboratory tests for the U.S. Department of Energy under Contract No. DE-AC05-840R21

How does foam facilitate high-performance buildings?

R-19 polyurethane & glass-fiber batt insulation:

Climate Temp (F) (68 F Inside Temp)	Wind Speed	R-Value – PU (2X4)	R-Value - Batts (2X6)
18	0	20.9	17.67
18	15	17.67	6.65
-15	0	19.95	12.73
-15	15	15.58	5.89

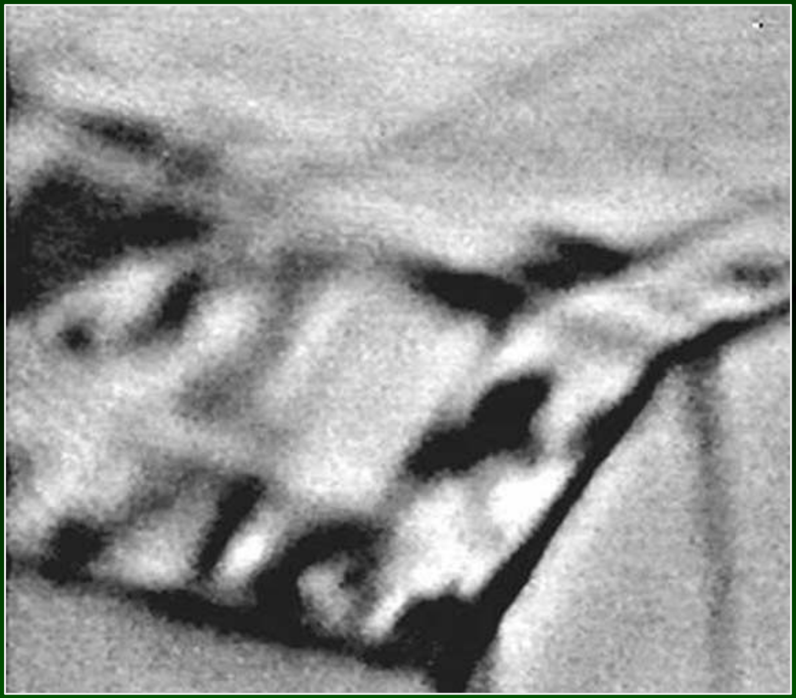
Architectural Testing, Inc. Test Results

How does foam facilitate high-performance buildings?

Convection reduces R-value, moves heat and moisture

How does foam facilitate high-performance buildings?

The effect of convection on R-value



Wind washing in batt insulation (strapping)

No convection in foam-filled roof cavities

How does foam facilitate high-performance buildings?

R=38 batts before (left) and after air sealing (right)

How does foam facilitate high-performance buildings?

2. The material has a broad range of application methods making it possible to solve many types of building envelope problems (injection, spray, sealants, open and closed-cell foam).
   a. Spray and injection application techniques
   b. Open and closed-cell versions
   c. Combined with QA, solves the majority of BE challenges

Field Applications

Spray-applied

- Requires open cavities.
- Requires OSHA-approved supplied air equipment and isolation of the work area. Depressurization can be used to protect occupied spaces.
- Allows application of desired R-value thickness.
- Allows visual inspection and infrared R-value and air leakage quality assurance.

Field Applications

The Spray-Applied (SPF) Method

Vented and unvented applications

Field Applications

Closed-cell in a 2x6 Wall - R-21 with no trimming

Closed-cell foam is a rigid product designed for interior and exterior applications. It expands at a ratio of ~30:1

Field Applications

SPF provides continuity even on complex substrates

Field Applications

Frozen-earth retaining application (The Big Dig)

Field Applications

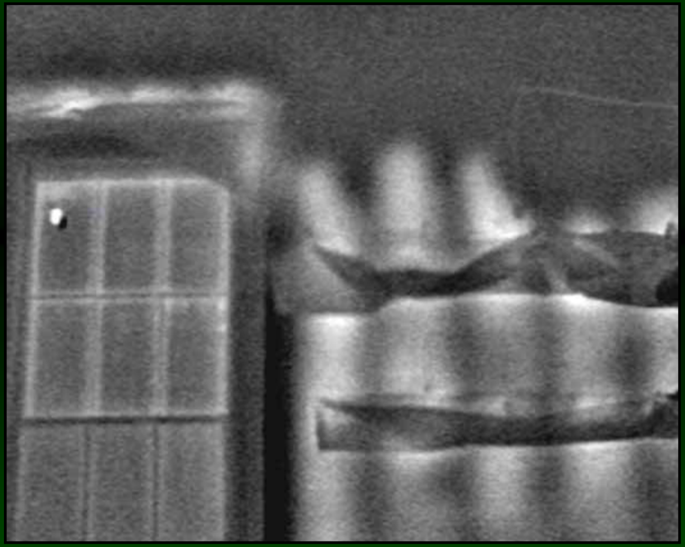
Underground Structures

Field Applications

Injected (cavity fill) on site

- Allows insulation, vapor control, and air sealing in closed building cavities.
- Requires ventilation of the work area. Depressurization can be used to protect adjoining occupied spaces.
- Requires filling closed cavities - R-value can be varied only by foam selection to match cavity thickness (if vapor issues allow).
- Requires infrared R-value and air leakage quality assurance (voids).

Field Applications

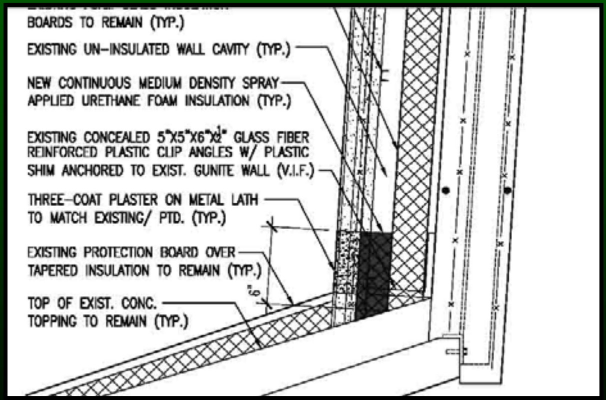


Infrared QA of foamed-in-place insulation – effective year-round (240F)

Field Applications

Infrared QA of foamed-in-place
insulation – effective year-round (240F)

Field Applications



Infrared QA of foamed-in-place insulation – effective year-round (240F)

Field Applications

Foam Sealant (SPF and FS)

- Bulk (SPF) – Spray foam applications makes sealing complex details manageable.
- Kits and cans (FS) – portable and low tech
- Requires ventilation of the work area. Depressurization can be used to protect occupied spaces.
- Requires infrared or pressurized fog testing for air leakage quality assurance.

*Handouts "Strategic Air Sealing"

Field Applications

How does foam facilitate high-performance buildings?

3. Advantages
   A. Works consistently and is durable
      a. Makes guarantees possible
      b. Meets the needs of prescriptive performance requirements like yours (note ASHRAE article)
   c. Effective in strategic BE improvement programs (Londonderry HS – 4% vs. 40%, batt insulation alone vs. with foam)

How does foam facilitate high-performance buildings?

Advantages

- Can be used below grade and in masonry construction without fear of damage from intermittent water exposure
- Bonds to surfaces - will not compress or settle.
- Chemical formulations can be tailored to the project needs – density, strength, permeability (dialing the right physical properties)

How does foam facilitate high-performance buildings?

Advantages

- Higher R-values are possible in smaller existing framing cavities.
- Works in roofs that are difficult or impossible to vent.
- Durable air-sealing capabilities, will not fail due to time, temperature, movement, or the cycling of building pressures.
- Will not be damaged by roof leaks, foundation leaks, or condensation.

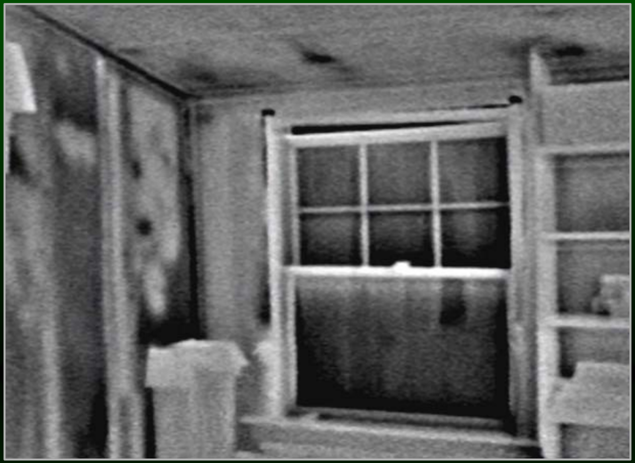
How does foam facilitate high-performance buildings?

Advantages

- Field-processed and field-applied
  - Continuous application for air barrier performance
  - Less complex and faster in complex locations
- Full range of installation techniques to address access challenges
- Quality assurance measures can be performed at any time of the year and during any phase of the construction sequence

How does foam facilitate high-performance buildings?

Thermal scan – before



Daylight view

Thermal scan – after foam

What can we achieve?

If we can provide predictable BE performance we can:

- Move toward achieving our NZE goal
- Cut overall up-front construction costs
  - Assure durability
  - Provide performance guarantees
  - HVAC system savings – downsized to tested levels
- Easily cut operating costs (25% to 75%)
- Avoid failures (localized and general)

What Can We Achieve?

At or near to net-zero energy buildings

What is cutting edge for overall building efficiency?

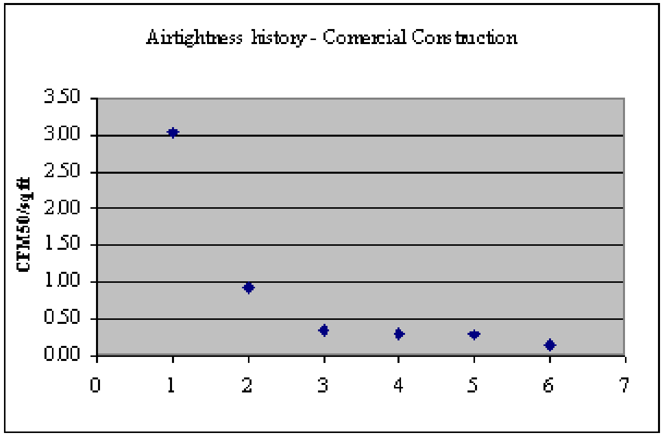
< 100 kWh/sq.m-yr total energy use

How do we achieve these goals? Do we target better R-value or less air leakage?

	R-value	ACH	UA	Total Btus	%
Standard R-value with standard air leakage					
Conduction				34,851,600	
Air leakage				38,237,184	
Total	19	0.50	60	73,088,784	100.00%
Standard air leakage with high R-value					
Conduction				23,234,400	
Air leakage				38,237,184	
Total	42	0.50	40	61,471,584	84.11%
				Improvement	15.89%
Standard R-value with low air leakage					
Conduction				34,851,600	
Air leakage				2,676,603	
Total	19	0.05	60	37,528,203	51.35%
				Improvement	48.65%

What can we achieve

	Commercial - History of airtightness	ACH Nat	CFM50/ Sq. ft.	ACH 50	KWH / SM/Yr.
1	ASHRAE study - Mean - US Commercial/Inst. (1998)	1.60	3.03	31.80	
2	Typical Commercial (2001)	0.43	0.93	4.75	
3	Efficiency Vermont typical baseline (new const. - 2003)	0.10	0.35	1.95	
4	ASHRAE 90.1 - Commercial (Recommeded - 2005)	0.10	0.31	1.90	
5	Average for modern high-performance Bldgs (2006)	0.07	0.29	1.32	
6	Target for current high-performance construction (2008)	0.05	0.15	0.90	<100



Note: some calculated ranges were averaged to allow graphing

This graphic shows how air barrier performance has improved over the last ten years

Consistent Performance

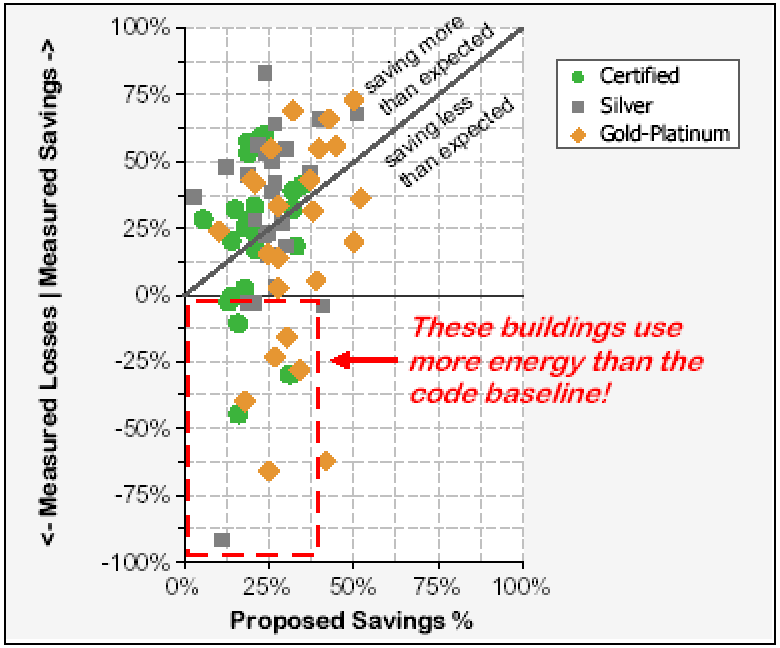


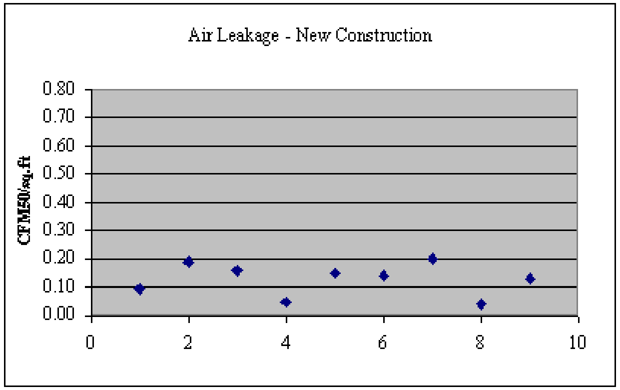
Figure ES- 5: Measured versus Proposed Savings Percentages

LEED Performance variation*

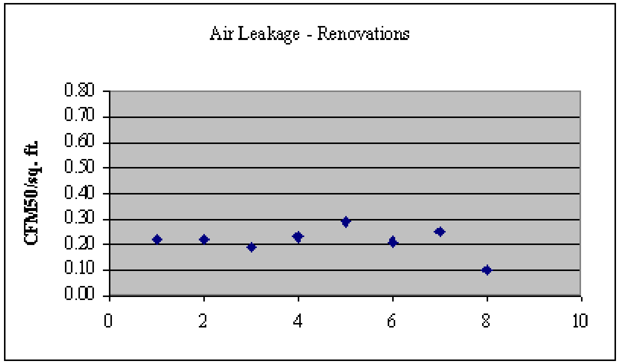
"Energy Performance of LEED® for New Construction Buildings," FINAL REPORT, March 4, 2008 (by: New Buildings Institute)

Consistent Performance

	BES - New Buildings, Major additions	CFM50/ Sq. ft.	ACH Nat	ACH 50	KWH / SM/Yr.
1	Logic Associates - Hartford, VT (84)	0.10	0.03	0.60	<100
2	Primex Office Bldg. – Concord, NH	0.19	0.06	1.15	
3	NRG Phase 1 – Hinesburg, VT	0.16	0.03	0.60	
4	Dartmouth – Kemeny (mockup)	0.05	0.02	0.27	
5	Champlain Valley Union HS	0.15	0.06	0.95	80
6	Richmond Middle School - No mech	0.14	0.04	0.88	
7	Randolph Development - Offices	0.20	0.06	1.15	
8	CRELL / NSF- Antarctica	0.04	0.01	0.25	65
9	Loudon Elementary (Addition)	0.13	0.04	0.80	
	Average	0.13	0.04	0.74	
	Standard Deviation	0.06	0.02	0.34	



	BES - Renovations	CFM50/ Sq. ft.	ACH Nat	ACH 50	KWH / SM/Yr.
1	Vermont Law School	0.22	0.06	1.26	
2	AVA Gallery	0.22	0.07	1.30	82
3	BES headquarters	0.19	0.02	0.50	
4	Phillips Exeter (Remodel)	0.23	1.70	1.45	
5	Williams College (Retrofit)	0.29	0.09	1.83	
6	Proctor Academy - Maxwell Savage	0.21	0.06	1.25	
7	Our Saviour Lutheran Church	0.25	0.07	1.50	
8	Waterbury Ice Center after air sealing	0.10	0.06	0.91	
	Average	0.19	0.26	1.03	
	Standard Deviation	0.05	0.58	0.28	



The small standard deviations of these projects demonstrate that it is possible to consistently meet industry targets for air barrier performance.

What can we achieve?

Insulation – R-value upgrades where cost effective.

Air barriers – Usually air leakage is the first place to look for large improvements.

Commercial	ACH Nat	CFM50/ Sq. ft.	ACH 50
Typical Commercial*	0.43	0.93	4.75
Efficiency Vermont typical baseline - new construction	0.10	0.35	1.95
ASHRAE 90.1 (Recommeded)	0.10	0.31	1.90
Average for modern high-performanceBldgs*	0.07	0.29	1.32
Target for current high-performance construction	0.05	0.15	0.90

Target for "cutting edge" structures – Better Buildings By Design 08	0.10
US Army Corp of Engineers number (.25 CFM @ 75 pa)	0.19

What can we achieve?

BES - New Buildings, Major additions, Renovations	ACH Nat	CFM50/ Sq. ft.	ACH 50	KWH / SM/Yr.
Logic Associates - Hartford, VT	0.03	0.10	0.63	5
Primex Office Bldg. – Concord, NH**	0.06	0.19	1.15	
Vermont Law School	0.06	0.22	1.26	
NRG Phase 1 – Hinesburg, VT	0.03	0.16	0.60	
Dartmouth – Kemeny (mockup)***	0.02	0.05	0.27	
Champlain Valley HS	0.06	0.15	0.95	80
Richmond Middle School - No mech	0.04	0.14	0.88	
Richmond Middle School w/mech	0.06	0.19	1.20	
Randolph Development - Office Building	0.06	0.20	1.15	
CRELL - ARRO prototype - Antartica	0.01	0.04	0.25	65
Kennett High School (Area A)	0.08	0.25	1.58	
Loudon Elementary (Addition)	0.04	0.13	0.80	
AVA Gallery	0.07	0.22	1.30	82
BES headquarters	0.02	0.19	0.50	
Phillips Exeter (Remodel)	1.70	0.23	1.45	
Williams College (Retrofit)	0.09	0.29	1.83	
Proctor Academy - Maxwell Savage Holland Hall	0.06	0.21	1.25	
Waterbury Ice Center after air sealing work	0.06	0.10	0.91	
Average		0.15		

What can we achieve?

Other - New Buildings, Major additions, Renovations	ACH Nat	CFM50/ Sq. ft.	ACH 50	KWH / SM/Yr.
Waterfront Apartments (Andy Shapiro)	0.03	0.12	0.58	
Ice Center of Washington West	0.04	0.14	0.80	
Wampanoag Tribal HQ	0.05	0.08	0.90	
College of the Atlantic	0.02	0.06	0.04	
NRG Phase 2 – Hinesburg, VT				
ET building				
White Pine CoHousing				
Average		0.10		

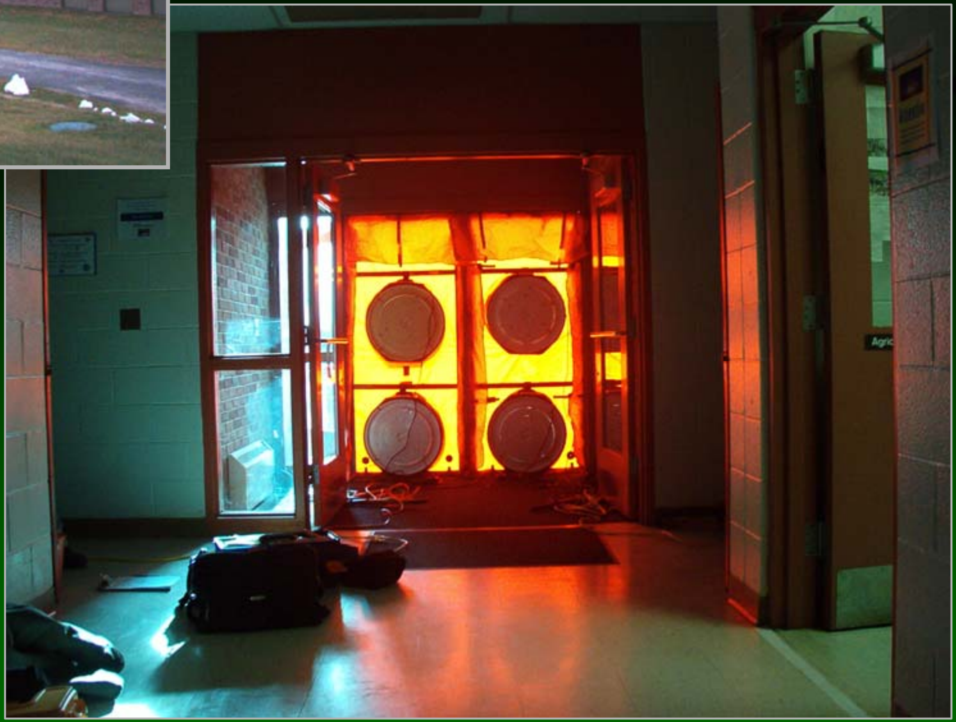
What Can We Achieve?

How do we know?

- We test large buildings, up to 200,000 sq. ft. to date, on a regular basis (before and after in retrofit situations).
- These projects include multi-fan whole-building and guarded-zone test procedures .
- We track energy use when available (before and after in retrofit situations).
- Examples
  - Kennett High School (200,000 sq. ft.)
  - White Mountain School (107,000 sq. ft.)
  - Park Avenue Armory (170,000 sq. ft)
  - Richmond Middle School (105,000 sq. ft.)
  - More in Case Studies

What can we achieve?

108,000 sq. ft. School

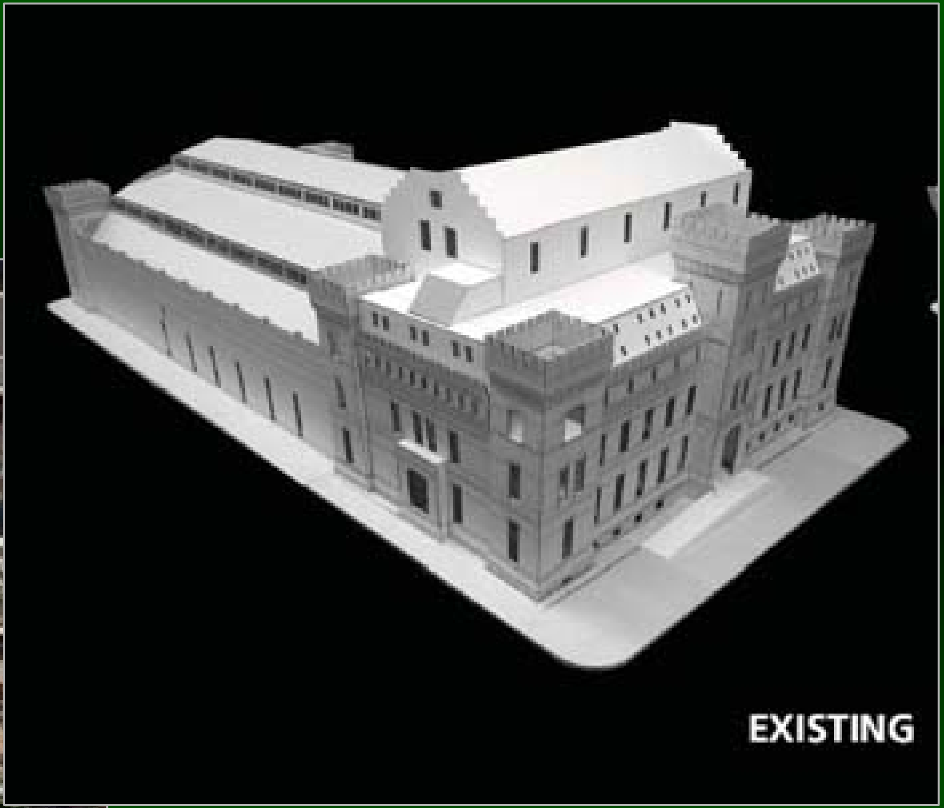


What can we achieve?

170,000 sq. ft. Park Avenue Armory

What can we achieve?

Occupies the entire block at Park Avenue & 67th Street, NYC



What can we achieve?

70,000 sq. ft. Drill Hall

What can we achieve?

18 fans used for guarded zone tests

What can we achieve?

What is the problem with our AB installations?

- **The air barrier system (if any) is typically incidental to the insulation and vapor retarder (American Ski)**
- **Air barrier systems are usually comprised of a complex number of materials with transitions not designed for continuity – multiple trades are often involved ("the old way in cavity-wall construction)**
- **Air barrier performance is typically not specified or required – no accountability**
- **Air barrier performance is rarely verified, so designers and installers usually don't know how well the system actually works (Dayco)**
- **Keep records (test and track air barrier performance by air barrier component – improved requirements)**

Side bar on blower door testing?

The Army Corp is developing its own method and reporting

- **Lead the way in the consistency of methodology and data collected.**
- **Settle on one unit of measure for each type of data (International).**
- **Standardize above and below-grade volume/surface area calculations and reporting.**

Report more than just the whole-building number.

- **With best practices, our buildings are getting tight enough that the "usual suspects" is shifting to areas that are not currently under industry pressure to improve.**
- **Test and track air barrier performance by air barrier component as well as the whole building. This is a no-cost or low-cost benefit that will direct your planning as you move forward. It will generate data that will tell you how much each component (windows, mechanical penetrations, etc.) contribute to your loads, and provide evidence to use in specifying minimum standards for sub components of the air barrier system.**
- **I suggest that your whole-building numbers be compared with mechanical systems unmasked (as used).**

What can we achieve?

What can we achieve?

Less complex

Standard construction in the north country – the interior BE

What can we achieve?

Very complex

Standard construction in the north country – the interior BE

What can we achieve?

Rigid Foam Board

Standard construction in the north country – the exterior BE

What can we achieve?

Standard construction in the north country – the exterior BE

What can we achieve?

Standard construction in the north country – the exterior BE

What can we achieve?

- Continuous
- monolithic air and vapor control system
- drainage plane

- High R-value/inch

What can we achieve?

Quality Assurance Testing

Methods

- Visual inspections
- First instance tests
- Thermography
- Blower doors
- Pressurized fog

Quality assurance is low-cost, is beneficial to all of the parties, and can be done any time of the year.

What can we achieve?

Test Methods

Problem	Test Method				
Ice Dams	Infrared	Blower Door	Fog Test	Monitoring Systems	Pattern Analysis
Pipe & Equipment Freeze-up	X		X	X	X
High heating and cooling	X	X	X		X
Drafty Buildings	X	X	X	X	
Rot, Mold and Bug problems	X		X	X	X
Excessive moisture/Condensation	X			X	X

What can we achieve?

Examples of Typical First-Instance Test Locations ("the usual suspects")

- foundation to wall
- window opening (56% at AVA)
- curtain-wall opening
- door opening
- wall to roof – gable end
- wall to roof – eave
- wall corner
- Roof-top and through-wall mechanical system penetrations and equipment (43% at MV)
- roof window
- additional details determined by the architect

What can we achieve?

Air Leakage Test Method

What can we achieve?

Pressurized Fog Analysis

What can we achieve?

First Instance Testing

What can we achieve?

First Instance Testing

What can we achieve?

First Instance Testing

What can we achieve?

First Instance Testing (window gaskets and AHU issues)

What can we achieve?

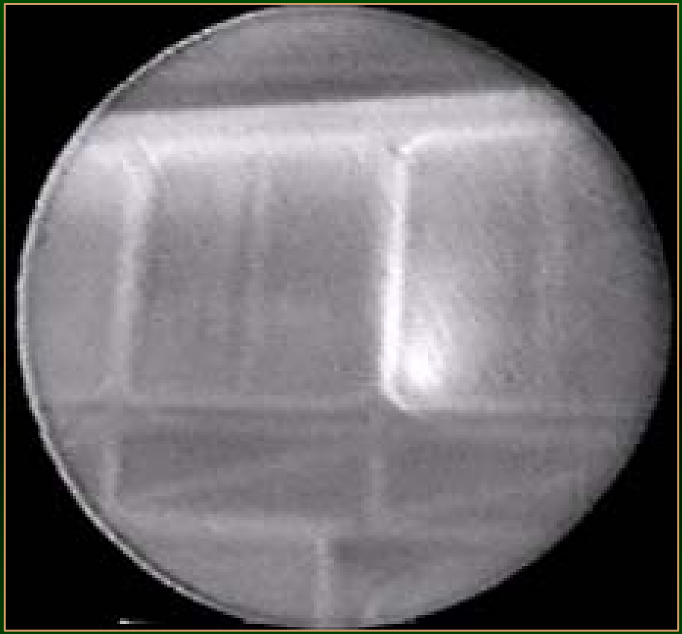
Pressurized Fog Analysis

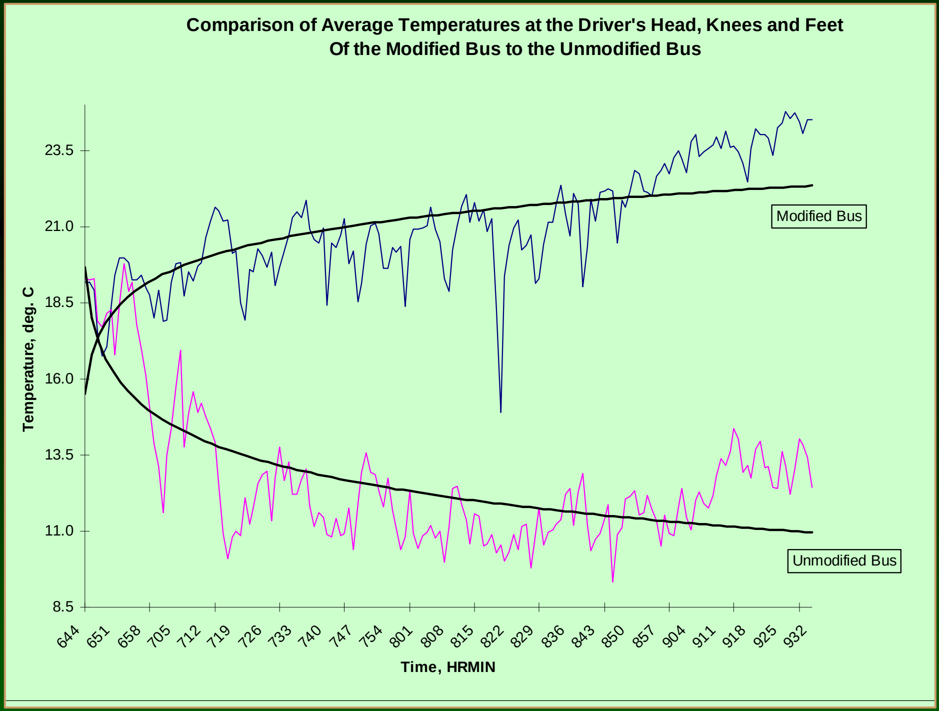
What can we achieve?

DARPA Testing

Pressurized Fog Analysis

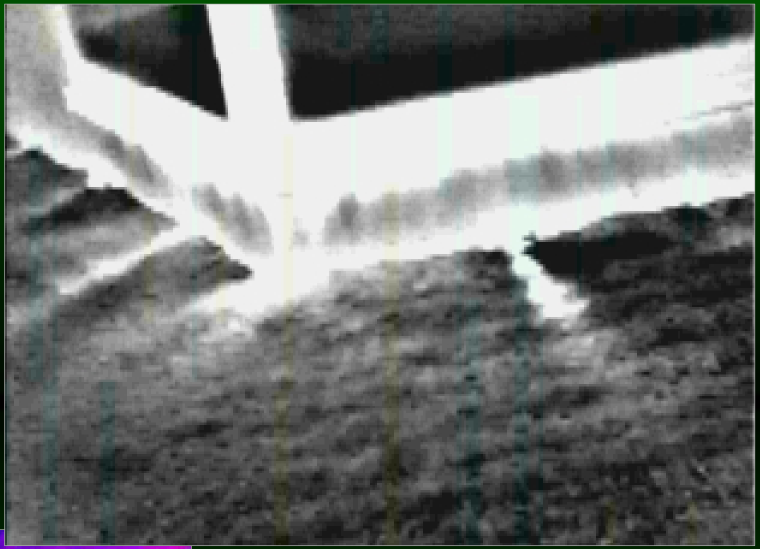
What can we achieve?

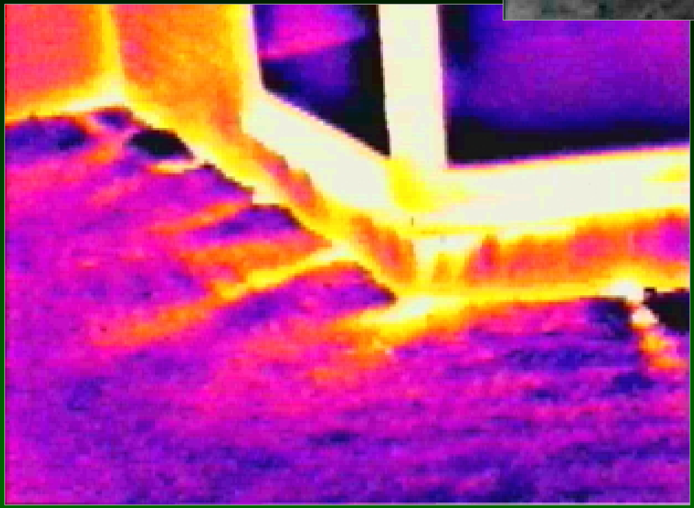




Results of the QA process

What can we achieve?





Technical Barriers

A. Limitation to processing
   1. Pass thickness
   2. Minimum and maximums temperature limits
      a. Extreme weather conditions
      b. Extreme substrate conditions
   3. Material compatibility and substrate conditions
   4. Air quality management required*
   5. Training* required for:
      a. Relatively technical process equipment
      b. Building Science implications
   b. Safety*
   6. Work-arounds for each

Technical Barriers

Pass thickness

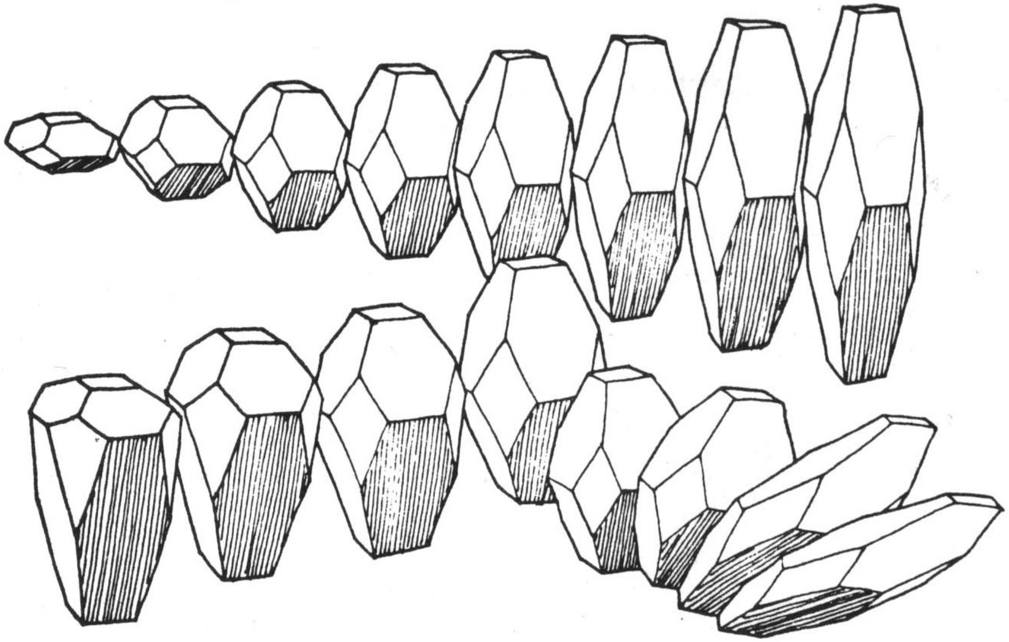


Figure 6-53. Examples of simple distortions of 4.6^2.

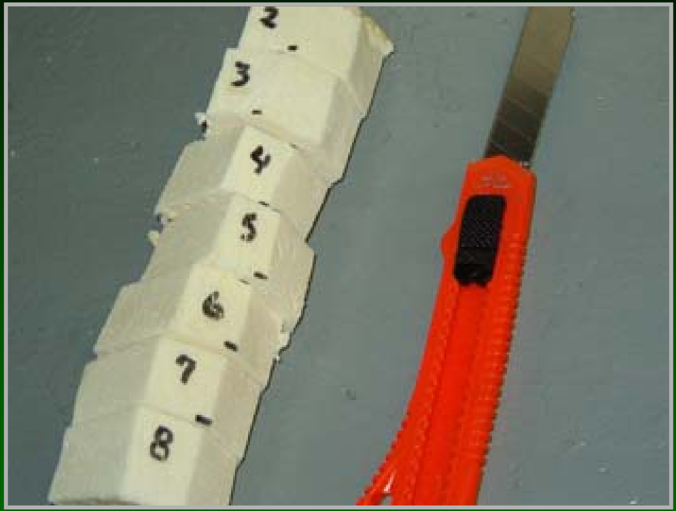
Elongated cells are stronger parallel to the long axis than perpendicular to it (similar to the grain in wood). Elongated cells usually mean improper application technique.

Technical Barriers

Elongated cells are weaker perpendicular to the grain and thermal shock causes the material to shrink laterally.

Technical Barriers

Density Profiles

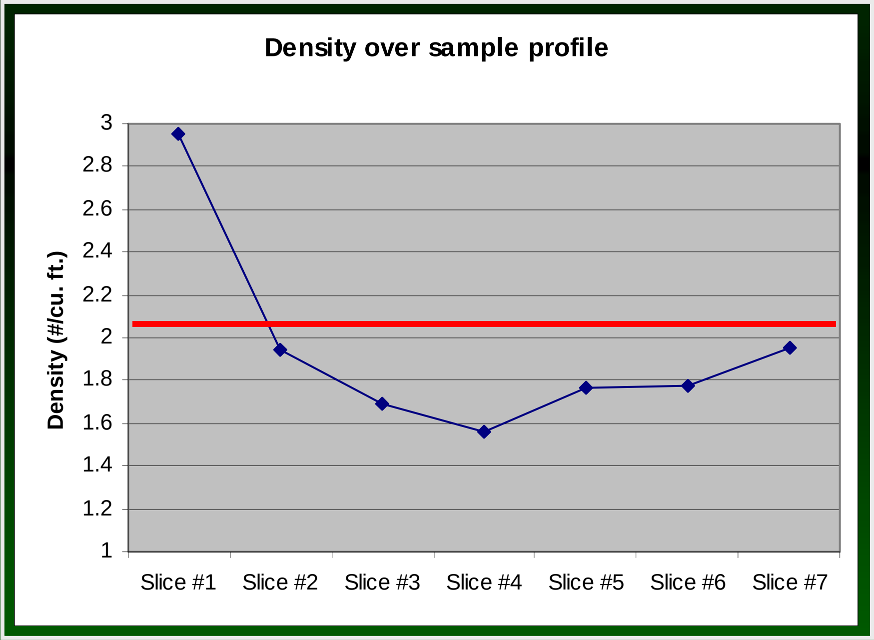


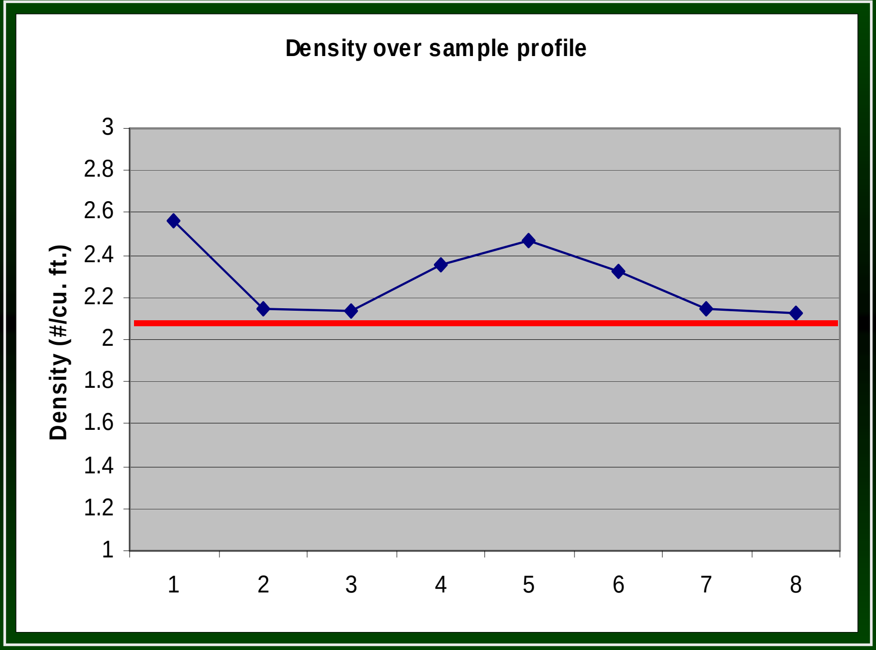
	Sample 10A	Sample 5B
Pass thicknesses	1.5" - 7"	1.5" - 2"
Percent change	6%	25%
Average density for entire sample	~1.8	~2.2
Slice #1	2.95	2.56
Slice #2	1.94	2.15
Slice #3	1.69	2.14
Slice #4	1.56	2.35
Slice #5	1.77	2.47
Slice #6	1.78	2.32
Slice #7	1.95	2.15
Slice #8	-	2.13

Technical Barriers

Density Profiles

Incorrect pass thickness





Correct pass thickness

Red line indicates minimum density (2.1#/cu. ft.)
for good dimensional stability

Technical Barriers

Incorrect pass thickness work-arounds

- Specify processing to mfg's specifications – but many get more specific for common problems.
- QA inspection reports for tested insulation thickness to include average pass thickness
- Require QA inspection record as a submittal

Technical Barriers

B. Concerns for the chemistry
   1. Prone to stratification when stored
   2. Must be the right temperature
      a. When stored
      b. When processed
   3. Work-arounds for each
      a. Specify processing to mfg's specs – but many get specific for common problems.
      b. Require process monitoring record as a submittal (datalogger output)

Technical Barriers

Is this a seasonal process?

- Polyurethanes can be typically be processed from 20 degrees to 95 degrees.
- Membrane applications have similar requirements to block and brick.
- Workaround – masons usually tent and heat in unusual conditions

Technical Barriers

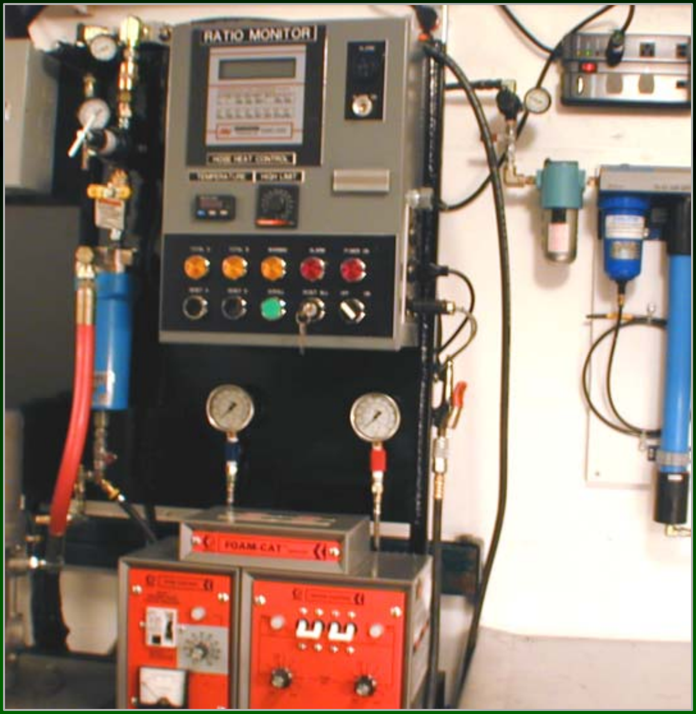
C. Quality assurance of installed materials

1. Equipment strategies and work-arounds
2. Process strategies and work-arounds
3. Installation strategies and work-arounds
4. Performance strategies
    a. Training
    b. Understanding how to implement the improved standards
    c. Intent communication

Technical Barriers

Equipment Quality Control Systems

Requiring industry-standard ratio-verified installations is the best strategy for verifying that installers provide quality processed material.



Ratio Monitor

Technical Barriers

D. Fire protection issues
   1. Exposed applications
   2. Understanding the code exceptions and rulings
   3. Knowledge of the protections available
      a. Coatings
      b. Other

Technical Barriers

- Exceptions to 15-minute thermal barrier requirement
  - Occupancy exceptions
  - Prescriptive PFI barriers
  - Other types of protection
  - Protect from ignition coatings or barriers
  - Using sheet goods as a work-around

Technical Barriers

- AHJs and consistency
- Test methods aren't up to current energy needs
- Minimum clearances - chimneys, etc.
- Safety in non-code applications (Unoccupied structures)

Technical Barriers

SPF with food-grade fire coating

Technical Barriers

E. Reversibility of renovation measures (Historic)
   1. Foam bonds to all compatible surfaces
   2. There are methods available to make the insulation removable, but still effective

Technical Barriers

F. Installer and occupant safety
  a. Safety equipment
  b. Air quality management*
G. DOT and OSHA requirements

SUMMARY

The family of polyurethane foam products provides a full range of solutions to building envelope (BE) requirements

- **Insulation (Open & closed-cell foam)**
- **Air leakage control (Open & closed-cell foam)**
- **Vapor control**
  - **By diffusion (Closed-cell foam)**
  - **By air transport (Open & closed-cell foam)**
- **Water management (Closed-cell foam)**
- **Structure (Closed-cell foam)**

SUMMARY

The family of polyurethane foam products provides a full range of solutions to building envelope (BE) requirements

- **Prevent air leakage with bulk foam and sealant formulations**
- **Manage vapor in bi-directional environments**
- **Are compatible with most building materials**
- **Can be used in conditions that are periodically exposed to bulk water**
- **Can be used in special conditions where drying is required**
- **Provide integral structural support for air barrier systems**

SUMMARY

- Proven technology
- Provides scientifically-correct BE solutions
- No technical barriers that can't be handled with standardized best practice procedures (training, specifications, and QA)
- Reliable solution for preventing building failures
- Better performance for less

Q & A

Champlain Valley Union High School

US Army Corps of Engineers ERDC-CERL

US Army Corps of Engineers ERDC-CERL

Energy Improvement vs. Cost

The Additions and Renovation of the Champlain Valley Union High School project (~63,000 sq. ft.).

The entire high-performance building envelope system was about $102,000.

The HVAC system cost at least 25% less than it would have with a conventional building envelope. This resulted in savings of $667,000.*

**Bill Root, GWR Engineering*

Merrimack Valley High School

Merrimack Valley High School

Stud backup wall

Merrimack Valley High School

Masonry backup wall

Merrimack Valley High School

Merrimack Valley High School

Merrimack Valley High School

First Instance Test

Energy Improvement vs. Cost

The Addition and Renovation of the Merrimack High School project (~90,000 sq. ft.). The total campus complex was 255,000 sq. ft.

The entire high-performance building envelope system was about $112,000.

The HVAC system cost at least 25% less than it would have with a conventional building envelope. This resulted in savings of $1,067,000.*

The first winter (2007-2008) the fuel cost for the campus was 21,000, or about $.10/sq. ft.

**Bill Root, GWR Engineering*

Loudon Elementary School

Masonry
backup wall

Compliance Test – Loudon Elementary School

Energy Improvement vs. Cost

The Addition and Renovation of the Loudon Elementary School project (~22,000 sq. ft.).

The entire high-performance building envelope system was about $60,000.

The HVAC system cost at least 25% less than it would have with a conventional building envelope.   This resulted in savings of $167,000.

Bill Root, GWR Engineering

Kennett High School

Kennett High School

Kennett High School

Kennett High School

Kennett High School

Kennett High School

Energy Improvement vs. Cost

The new Kennett High School project (~200,000 sq. ft.) in Conway, NH.

Our tests indicated that the installed air tightness was 20% tighter than the new ASHRAE recommendation and 70+% tighter than “typical construction.”

This building cost approximately $32,000,000.

The entire building envelope system for the walls was installed by the contractor for about $350,000.

The savings in the up-front construction costs should be at least $500,000.”

Techniques 1 - Extreme makeovers

Billings Farm – Now surrounded by an office complex.

Logic Associates (1984)

Techniques 1 - Extreme makeovers

Logic Associates (1984)

Techniques 1 - Extreme makeovers

Logic Associates (1984)

Techniques 1 - Extreme makeovers

Logic Associates (1984)

Techniques 1 - Extreme makeovers

Extreme makeovers – Logic Associates (1984)

ACH Nat	CFM50/ Sq. ft.	ACH 50	KWH / SM/Yr.
0.03	0.10	0.63	

Target for "micro load" structures – Better Buildings By Design 08	**0.10**

Logic Associates (1984)

Kennett High School

Summary	Estimated Standard Construction	Actual H-P Construction
Total HVAC system cost	$533,333	$400,000
Total Shell	$44,067	$132,200
Total HP design and commissioning	$0	$2,000
Total Additional work by BE related trades	$0	$12,100
Total Shell & HVAC system cost	$577,400	$546,300
Total net additional cost or savings		$31,100
Square foot costs ($/sq. ft. of floor area)		
Building	$98.75	$97.99
HVAC systems	$13.07	$9.80
HP Shell including all related costs	$1.08	$3.58
Subtotal	$14.15	$13.38
Savings		$0.76

Kennett High School

Performance Data	Other Construction	Actual H-P Construction (tested)
Air Leakage Rates (in CFM50/Sq. Ft. of shell)		
Third-party Compliance Test Result	-	0.22
ASHRAE Recommended Max. Leakage	0.31	-
Conventional Construction - US average	0.93	-
By building component		
Windows		1.110
Rest of shell (including HVAC)		0.109
By building component (CFM leakage)		
Windows & doors	3,772	56.1%
Rest of shell (including HVAC)	2,949	43.9%
Total CFM leakage	6,720	
Total Energy use (KWH/SM/Year)*		81.99
*GWR Engineering		
*LEED Certification calculation (Energy Star Energy Performance Tool)		

Reaching diminishing returns on walls and roof

ARRO 1 & 2

Autonomous Real-time Remote Observatory (ARRO) instrument shelter for deployment in Antarctica. Case study (south pole) net-zero energy research facility

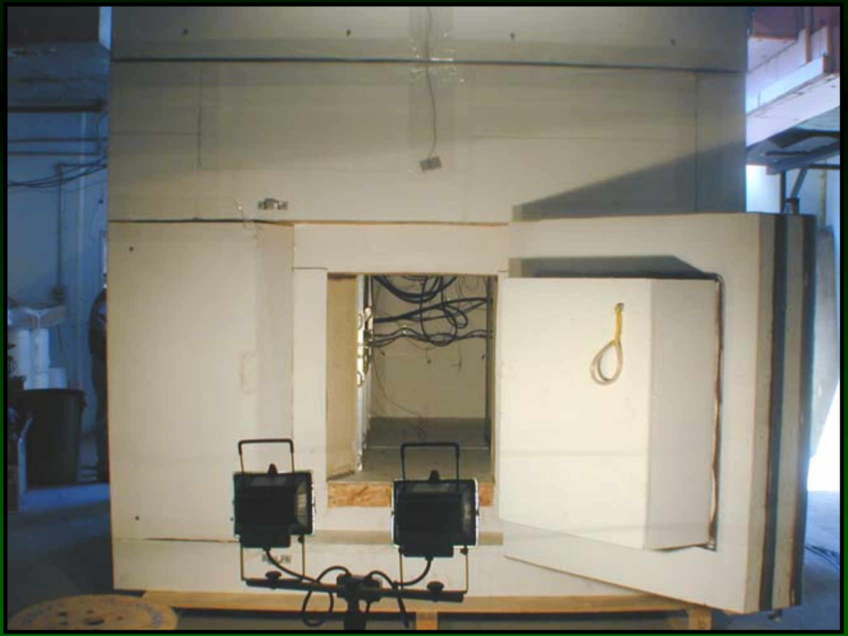
ARRO 1 & 2

- The first ARRO Project being tested at CRREL

200 watts for –70F outside, 70F inside.

ARRO 1 & 2

- The first ARRO Project being tested at CRREL



200 watts for –70F outside, 70F inside.

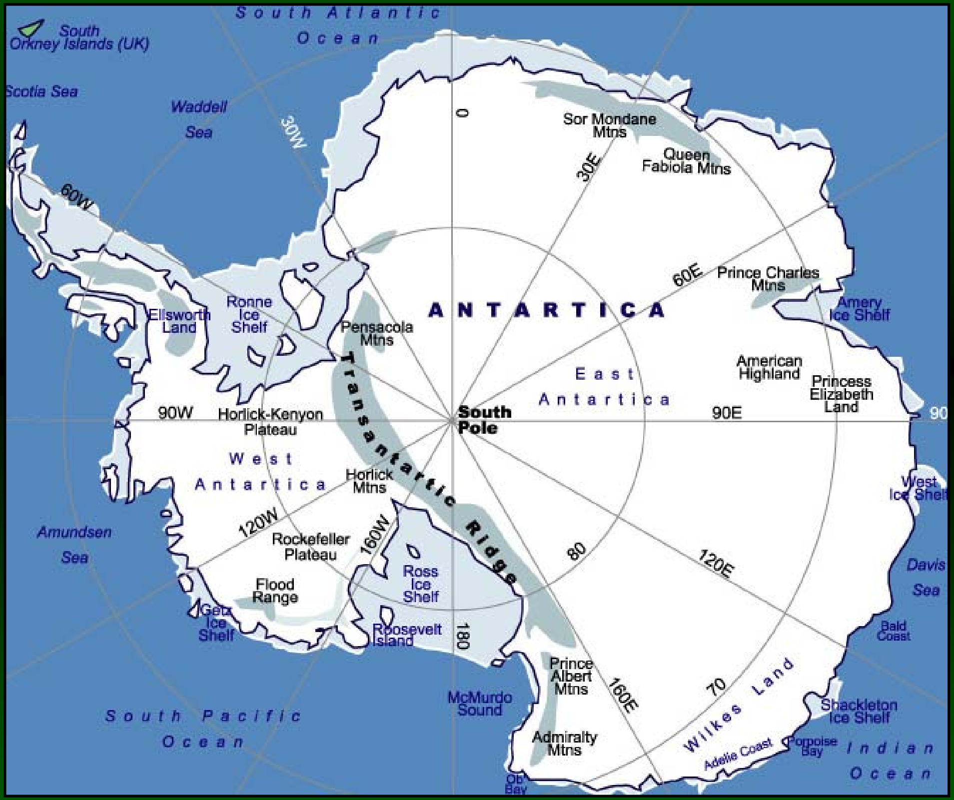
ARRO 1 & 2

General Project Information	
Project/Client Name	ARRO 1
Location	Antarctica
Date project completed	January-08
Type of construction	Prefabricated panels
Total sq. ft. - Useable floor area	81
Total sq. ft. - Above-grade shell	
Total sq. ft. - Roof	81
Total sq. ft. - Walls	312
Total sq. ft. - Floor	81
Total sq. ft. - Glazing area and doors	12
Total	486

ARRO 1 & 2

US Army Corps of Engineers ERDC-CERL

ARRO 1 & 2



Funded in part by the National Science Foundation

ARRO 1 & 2

Funded in part by the National Science Foundation

US Army Corps of Engineers ERDC-CERL

ARRO 1 & 2

Funded in part by the National Science Foundation

US Army Corps of Engineers ERDC-CERL

ARRO 1 & 2

Funded in part by the National Science Foundation

The ARRO 2 Project is part of the development of a new high-performance building system intended to be made available to the general public.

ARRO 2 “Panel-Block” Performance Data

R=70, .05 cfm50/sq. ft. air infiltration rate, competitive construction costs.

TECH-FORMS

US Army Corps of Engineers ERDC-CERL

TECH-FORMS

TECH-FORMS

TECH-FORMS

TECH-FORMS

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TECH-FORMS